DEVELOPMENT OF A PORTABLE INFRARED SURVEILLANCE SYSTEM WITH AUTO TARGET CUEING CAPABILITY

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ABSTRACT

In this work, we are developing a multi-function, dismounted system for longwave infrared (LWIR) surveillance with auto target cueing capability. The system consists of two main parts (1) electro-optical (EO) system and (2) image processing unit. Integrated with the uncooled LWIR imager in the EO system is a Thales MELT laser range finder, electronic compass and GPS module for additional target information. The azimuth and elevation of the unit are tracked by two angle encoders integrated to the EO system tripod. IR digital video and other information are sent to a laptop computer for real time video and target processing by the auto target cueing algorithm. We present the system architecture, software configuration, in addition estimated and measured imaging system performance. The system will be ready for field trials in summer 2009.

1. INTRODUCTION

In order to take advantage of ongoing advancements in sensor technologies and materialize these as improved soldier capabilities, military research and development focuses on upgrading data to knowledge, device miniaturization and weight reduction. Integrated solutions offer multi-purpose and multi-role uses to reduce numbers of systems carried and soldiers' workloads in theaters. Furthermore, as industries continue to develop miniaturized, high performance, yet low power consumption and low cost electronics, more data processing power can be integrated in today's soldier systems with purposes on filtering, converting and enhancing data into useful information and knowledge. All these developments make more capable, portable and "intelligent" future soldier systems that further reduce soldiers' workloads and resemble human brain functions. Simultaneously, tremendous information is collected by a man's five senses (persistent surveillance) in the background and processed by the brain without our conscious awareness, and only the pertinent portions are brought to our attention.

In this work, we are developing a multi-function, portable system for longwave infrared (LWIR) surveillance with auto target cueing capabilities. These capabilities include multiple target detection, tracking, and classification (human, vehicle, or clutter). Other components were also integrated to the system to provide additional target information. The real time video processing algorithm was developed under the ongoing Advanced Linked Extended Reconnaissance and Targeting Technical Demonstration Project (ALERT TDP) at DRDC since 2003. This algorithm, originally designed for surveillance and reconnaissance vehicles in the context of ALERT, will be optimized for high-end laptop computer. Some tradeoffs on performance will be considered. As a portable system, it could facilitate dispersed and dismounted surveillance missions of soldiers at observation posts or cue command post on target information as man-operated or unattended system.

2. CAPABILITY DEMONSTRATION: CONCEPT, CONSIDERATION AND ISSUES

The goal is to design a system that demonstrates and validates the potential of a portable electro-optical (EO), auto target cueing system in various dismounted soldier or standalone operations. Such roles extend from peacetime military engagement, peace support, counter insurgency

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(COIN), to major combat operations, as well as non-military roles such as national security of a major international event, border surveillance and sovereignty protection. Besides the technological functions brought by electronics and sensors, the most important, measurable success will be to quantify the amount of reduced workload, stress, elevated performance on surveillance tasks (Sense) and improvement on find-fix-engage chain (Act). These will be studied in trials in conjunction with human factors.

For surveillance, an EO system should first cover a wide angle or wide field-of-view (WFOV). Upon detection, enhanced target details could be obtained by electronically or optically zooming (Narrow field-of-view NFOV). The latter detailed target image will allow high accuracy in auto target cueing tasks. However, with today's COTS uncooled LWIR 640 by 480 arrays and soon wider availability of 1024 by 768 arrays, unfortunately, it is not feasible to have both WFOV and NFOV using one single detector array. The reason is that the number of detector elements of the focal plane array (FPA) is still not sufficient. If the EO system optics is configured for WFOV and electronic zoom is used for NFOV, detailed target image is possible only at short standoff distance, which is not useful. In the case of optical zoom, it requires a complex (and heavy) lens system to perform quality, optical zoom between WFOV and NFOV in LWIR. The optimization of image quality with consideration of optical diffraction between 8 and 12 µm is also very challenging.

It is clear that we will need one WFOV and a separate NFOV LWIR channel. This is now a viable and affordable option with the reduction to detector costs. The WFOV channel will be used to perform search and surveillance. Upon detection, the NFOV channel will be used to collect high resolution target image for classification and recognition tasks. In future, it will be possible to use one single channel and electronic zoom when higher resolution detector arrays are becoming available. The optics should be selected to provide up to 5km and 1km in auto target cueing mode for detection and recognition, respectively. These ranges should be sufficient in many scenarios.

It is planned to have target geo-position calculated in future work therefore, a few electronics components are needed to provide additional target information for this purpose. Upon detection, the laser range finder (LRF) is used to determine target standoff distance. Electronic compass and GPS information provide additional target information that may help to classify, identify and verify a target. Angle encoders with high precision complement the electronic compass. Images and video is stored with target attributes (time, location, classification, etc.), and it is planned to use wireless link to send target information to a command post, or directly to operational database (ODB).

With the above consideration, the auto target cueing EO system was designed to have two LWIR channels, LRF, electronic compass, GPS, angle encoders to track system azimuth and elevation, and effective ranges of 1 and 5km for target recognition and detection.

3. EO SYSTEM ARCHITECTURE

The system consists of two main units (1) EO system unit and (2) image processing/system control unit. The overall EO system unit architecture is illustrated in Fig. 1. Two ULIS uncooled LWIR microbolometer FPAs were used in separate WFOV and NFOV IR imaging channels. These FPAs are the newest 640 by 480 FPAs from ULIS with 25µm pixel pitch and 50mK noise equivalent temperature difference (NETD) rated at f/1, 300K and 60Hz. Custom FPA proximity electronics was designed and fabricated by Institute Nationale Optique (INO) with Camera Link data output at 14-bit data transmission at 60Hz. Two commercial-off-the-shelf (COTS) germanium lenses were selected from Ophir Optics Group. The Ophir SupIR 75mm (93% LWIR transmission and f/1) and SupIR 114mm (87% LWIR transmission and f/1) lenses were designed for 640 by 480 25µm pixel pitch FPAs providing horizontal FOVs of 11.5 and 8.0 degrees, respectively. Integrated in the imaging unit is a Thales MELT LRF, electronic compass and GPS module for additional target information. This unit will use COTS $LiSoCl_2$ 10.8V battery for dismounted mission. A DC power input is also available. The unit will be mounted on a tripod to where two optical angle encoders from Heidenhain Inc. were integrated to track azimuth and elevation of the unit. All these low bandwidth peripherals are controlled by a PC104 integrated inside the unit. IR digital video and other information are sent to a laptop computer through GigE cable. No target geo-position calculation is performed for now but could be pursued in next stage. Video processing on target cueing, and camera and peripherals setting and control will be carried by the laptop computer.

Fig. 2 and 3 show the system configuration of all the components of the EO system unit. The unit was estimated to weigh about 14kg with battery and to have a form factor of one cubic foot. The housing was designed for weather resistance. The system operating environment was planned for ambient temperatures between -20 and 50 ^{o}C and humidity between 0 to 80%. Non-magnetic materials and parts were used to build the system unit to avoid possible interference towards the electronic compass readings.

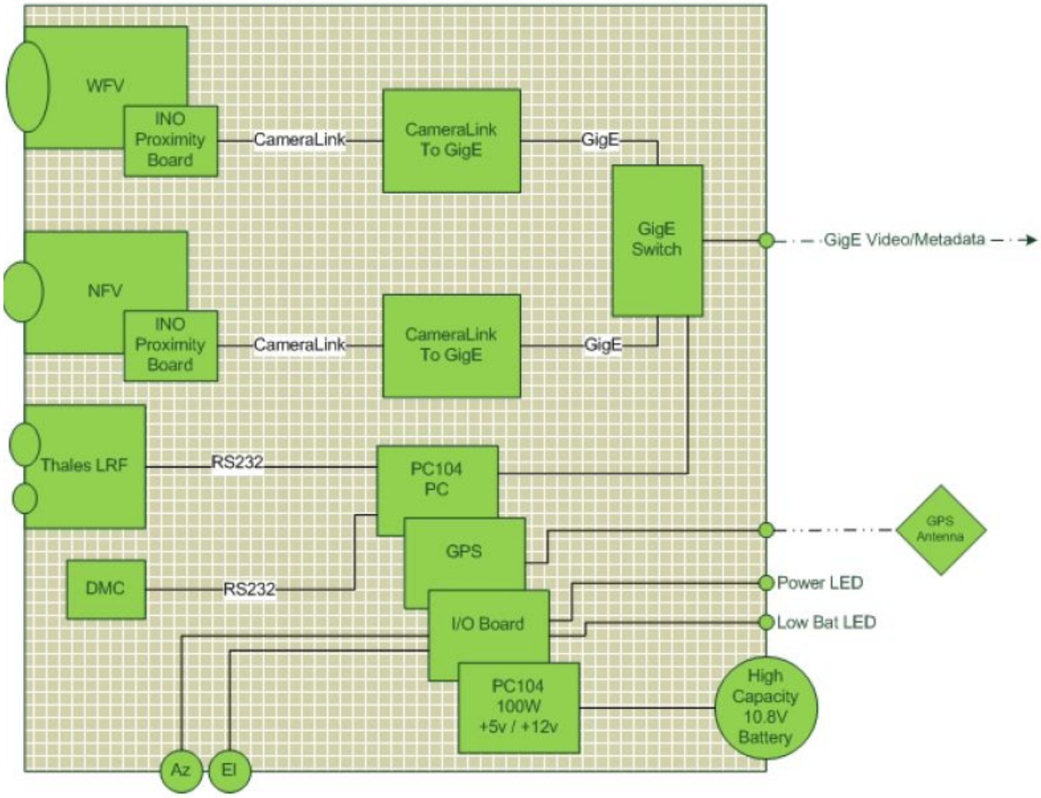

Fig. 1 System architecture

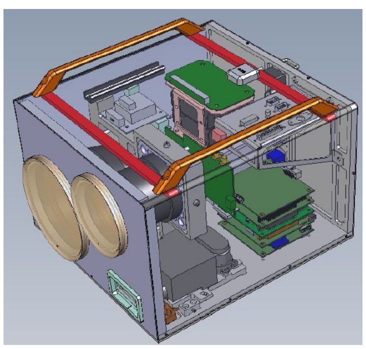

Fig. 2 EO system unit front view

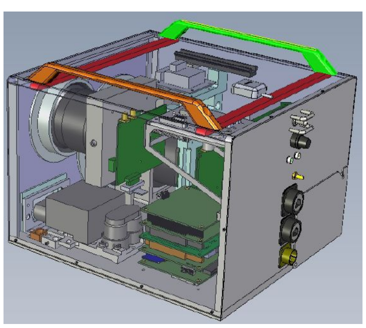

Fig. 3 EO system unit back view

4. SOFTWARE ARCHITECTURE

The application software of the auto target cueing system consists of two components (1) data acquisition and control processing and (2) auto target cueing processing.

4.1 Data acquisition and control processing

The digital video raw data and other peripheral information will enter the laptop through the GigE bus (see Fig. 4). Image raw data will be processed to create images and videos for display by a frame grabber. Peripheral data and control, and camera control commands are passed via the same GigE bus between the EO unit and the laptop. The processed video data is stored in shared memory in the laptop that the auto target cueing algorithm will access.

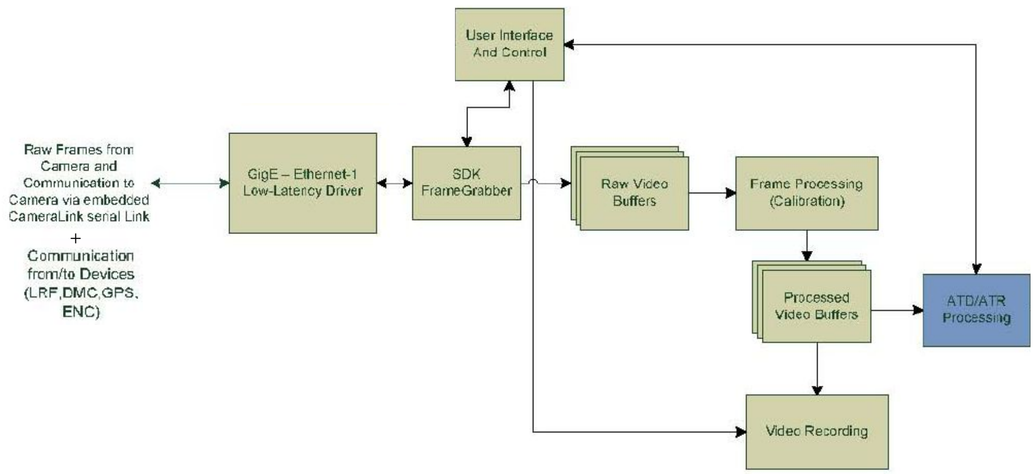

Fig. 4 Data acquisition and control processing

4.2 Auto target cueing processing

The auto target cueing algorithm (ATC) was developed under the ongoing ALERT TDP at DRDC debuted in 2003. The ATC algorithm draws operator attention to a particular area of interest where computer algorithms processing the IR- or visible-band images have detected and possibly classified a target.

Originally designed for surveillance and reconnaissance vehicle, the algorithms will be optimized for high-end laptop computer and some tradeoffs (e.g. frame rates or encoding bits, etc.) on performance will be considered. The current algorithm could process IR video at 30Hz at resolution of 320 by 240 and provide real time target detection, tracking and classification (human, vehicle, and clutter).

The current structure of the automatic target detector (ATD) and classifier algorithms used for ATC are presented in Fig. 5. Within this approach, images are first enhanced with an auto-adjust contrast algorithm. They are then registered and processed to compute a background image estimate. Used as a reference, the latter is subtracted from the registered images and the result goes through an adaptive-threshold image binarization method based on the noise statistic of previous image differences. This process indicates any potential moving objects.

A morphology filter is then applied on the binary image to remove irrelevant objects (blobs less than 1.5 cycles) and to agglomerate adjacent blobs into larger objects. Moving objects or blobs are modeled as a box with centre pixel coordinates, width and height. These blob characteristics are computed in the blob analysis module. The tracker receives the blob information and tracks objects along time, based on a singular value decomposition (SVD) process that maximizes the correlation between inter-image blob characteristics. To be declared a potential target, a blob must be tracked in several images (at least five for now).

Within the classifier, image chips (valid targets) are then extracted from the registered images using blob characteristics and finally classified into three categories. These categories are vehicle, human and clutter. At the end of the ATC process, only the vehicle- and human-class object positions are sent to the display processing unit.

Within the scope of the ATC optimization process, the detection and classification algorithms have to be assessed for detailed characterization of strengths and weaknesses. This assessment is required for optimizing and for selecting the appropriate classifiers and ATD components for integration within the EO system.

Emphasis is placed on collecting image sequences that would permit assessing ATC performance for perimeter surveillance scenarios and present a large variability in conditions. Image sequences containing moving and stationary targets (human or vehicle) and scene change are of special interest. Within these sequences, targets of interest could be either unobscured or of low contrast, partially concealed, dug-in, and may have had their signatures modified by the addition of local vegetation.

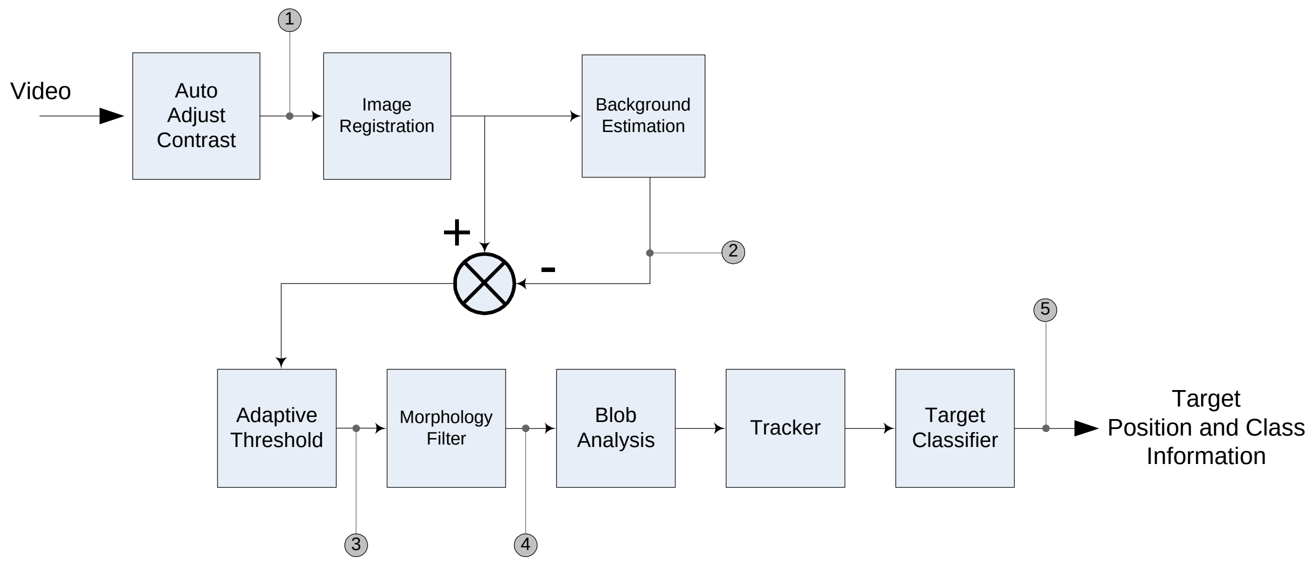

Fig. 5 The structure of the ATC algorithm

A database application was developed to store and manage digitized image sequences, and assist in algorithm assessment. The database architecture includes the essential entities, attributes, tables and relationships required for maintaining related records of sensor and digitizer data, information on image sequences, image truth, target characteristics, image characteristics, scores and ATD/classifier decisions, and weather data. Built-in specialized tools automatically compute image characteristics, manually extract truth data, and create training and test image sets. Generating “image truth” data refers to specifying for every target in an image the target type, target location (pixel location), and if possible the target range, heading and velocity. Data for target characteristics includes the position and dimension of the target-bounding box or scoring window, target obscuration, turret position (if available), and characteristics within the scoring window such as pixel peak intensity, minimum intensity, mean intensity, standard deviation.

The testing and scoring ATD or classifier algorithms are carried out by running the algorithms with image sequences stored in the database, and measuring the exactness of the algorithm’s decisions. For every image, the number of correctly-detected targets, the number of missed targets, the number of declarations that were not targets (false alarms) and target identification are recorded and managed in the database for later analysis. Algorithms are scored by the calculation of simple statistics based on the correct detection and identification of targets and the production of false alarms, which yields actual performance measures such as receiver operating characteristics (ROC) curves and confusion matrix.

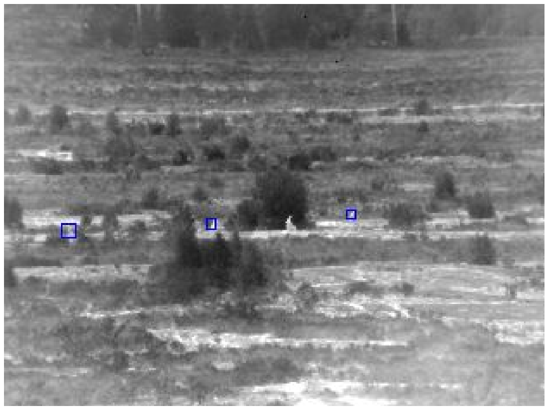

Fig. 6 A team running across in front of the camera

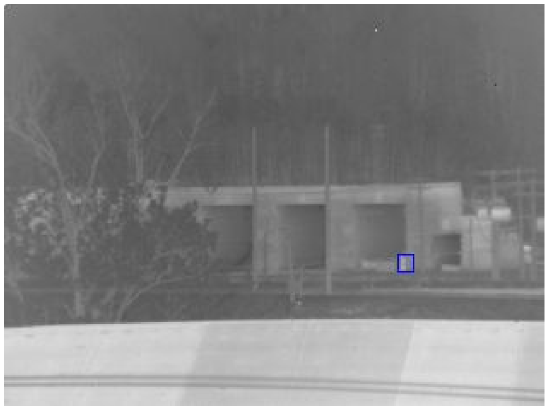

Fig. 7 A man walking across in front of the camera

To date, 250 sequences (providing over 20 000 images) were recorded and image truthed for algorithm development, optimization and performance estimation. There are typical image sequences to be processed by the EO system. The data set includes color and IR sequences recorded in desert, forest and urban environments. Fig. 6 and 7 show two images captured from video streams in which men were detected, tracked and classified.

5. PERFORMANCE ESTIMATION

EO imaging system performance was estimated using known parameters and presented here. Field trials will be carried out in 2009 to obtain realistic target detection and recognition ranges, and LRF and compass accuracy for validation.

5.1 Estimated range performance

With the EO system parameters, we can estimate target detection and recognition standoff ranges. Here NVThermIP (Jan 2006 version) of US Night Vision and Electronic Sensors Directorate was used to calculate the ranges. Assuming a target size of 0.85m wide for a man and 2.3m wide for a vehicle and using the Targeting Task Performance (TTP) V50 standard of 2.7 cycles for search and detection, and 14.5 cycles for recognition range, Table 1 shows the calculated target search and detection, and recognition range with the associated WFOV and NFOV of the EO system, for a 50% probability of correct target detection or recognition. Atmospheric transmission and target contrast were assumed to be 80% and 2 degrees, respectively. Constant gain was used in the simulation. With these range values, it shows that this configuration should provide the desire detection and recognition ranges under most situations. In addition, the MELT LRF with a maximum range of 20km is sufficient to cover the system range of interest.

Table 1 Range estimation on target detection and recognition based on V50 with WFOV/NFOV

	Man	Vehicle
	WFOV (km)	WFOV (km)
Detect	1.7	3.7
Recognize	0.7	1.7
	NFOV	NFOV
Detect	2.3	4.8
Recognize	1.0	2.3

As the required cycles for the auto target cueing process (recognition) in some situations are less than those estimated for an operator in NVThermIP, it will be interesting to see if the system can automatically detect and classify a target at longer standoff distance and higher probability of success compared to those determined by an operator.

5.2 Measured MTF, NETD, SiTF and MRTD of EO system

The modulated transfer function (MTF) is a measure of the system response on the spatial frequency domain. An edge target is used to produce a step function in the image captured by the EO system. The MTF is then obtained by calculating the Fast Fourier Transform (FFT) of the derivative of the step function. The noise equivalent temperature difference (NETD) expresses the detector noise in term of temperature contrast. It is directly related to the detector's detectivity and represents generally the temporal noise of one pixel. Modern FPA sensors will exhibit complex noise patterns that are not described by the classical NETD parameter. These noise patterns that are due to FPA reading process or FPA spatial non-uniformity will greatly influence the image quality. The signal transfer function (SiTF) measures the linearity and the dynamic range of a system. In the present case, only the maximum temperature ranges will be measured for the minimum and maximum gain settings. The minimum resolvable temperature difference (MRTD) measures the temperature contrast response of a system as seen by an operator. This measure includes the complete imaging loop (optics, FPA response, noise, processing, display, etc.). This measure is of a primary importance in performance prediction.

The measured data is not available before the deadline of the manuscript submission. This data will be presented at the conference poster session.

6. DISCUSSION AND CONCLUSIONS

A first portable LWIR imaging system with real time auto target cueing capability was designed. Imaging and non-imaging hardware were tested and preliminary performance estimated. The optimized auto target cueing algorithm and user interface incorporating both command and control, and target image processing will be completed by early 2009. Field trials will be performed in summer 2009 to validate the performance.

In the context of Sense, this portable system could be tested in several simulated soldier missions to determine the improvement on dismounted and standalone surveillance operations.

(1) Perimeter surveillance I – The system will be used in general surveillance missions with the presence of soldiers (Attended mode). Upon target detection and classification (human and vehicle) with clutters filtered out, operators will be notified for verification and actions (target confirmation and identification, laser ranging the target, contacting command post, etc.). In this case, in long endurance mission and scenarios, soldiers do not need to

watch the monitor continuously (a source of serious fatigue). Since the system is man portable, we can move the observation post easily and quickly according to mission status.

(2) Perimeter surveillance II – The system will be used in general surveillance missions without the presence of operators (Unattended mode). Upon target detection and classification, the system will trigger the LRF to determine target standoff distance and send all target information to the command post through secured wireless link. It is noted that the system will require a pan-and-tilt module to complete this task as we need to point the LRF to the target.

In the context of Act, this capability on portable weapon systems may be evaluated to determine if the find-fix-engage chain can be more efficient.

(3) Weapon cueing I – Although the system is not yet compact to be tested on assault rifles and light machine guns, we foresee this as a first step towards future use, in a miniature version, with heavy machine guns, crew served weapons such as grenade machine gun (GMG). This will help us determine if a sight with auto target cueing capability will improve the task performance. The targeting ranges of system are sufficient compared to these weapon effective ranges.

(4) Weapon cueing II – A thermal sight with integrated fire control system (FCS) was presented and tested on a GMG [1]. In this work, it showed improved accuracy on effect delivery. This is yet another example of the possibility of having enhanced capabilities integrated in dismounted systems. Upon a satisfactory demonstration on portable auto target cueing capability, it is evident that, in a future auto target cueing and FCS integrated system, this capability will assist soldiers to efficiently locate targets for which the FCS will determine the ballistic solutions.

Whether it is for weapon cueing or surveillance, it is noted that the networked nature of this system (GigE) enables operators to view and change sensor channels remotely, from multiple authorized locations, fitting precisely into the network enabled battlefield.

The prototype unit presented in this work would be a baseline system to be used for performance evaluation and validation on several warfighting operational concepts. In addition, with the ongoing improvement on electronics, future system will only be more compact with superior processing capability yet low in power consumption. It will be possible that a hand portable, or helmet or rifle mounted unit can be realized in the future for reconnaissance and tactical missions.

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